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V. A Proposition of General Use in the Art of Gunnery, shewing the Rule of Laying a Mortar to pass, in order to strike any Object above or below the Horizon. By E. Halley.

IT was formerly the Opinion of those concerned in Artillery, that there was a certain requisite of Powder for each Gun, and that in Mortars, where the Distance was to be varied, it must be done by giving a greater or lesser Elevation to the Piece. But now our later Experience has taught us that the same thing may be more certainly and readily performed by increasing and diminishing the quantity of Powder, whether regard be had to the Execution to be done, or to the Charge of doing it. For when Bombs are discharged with great Elevations of the Mortar, they fall too Perpendicular, and bury themselves too deep in the Ground, to do all that damage they might, if they came more Oblique, and broke upon or near the Surface of the Earth; which is a thing acknowledged by the besieged in all Towns, who unpave their Streets, to let the Bombs bury themselves, and thereby stifle the force of their Splinters. A Second Convenience is, that at the extreme Elevation, the Gunner is not obliged to be so Curious in the Direction of his Piece, but it will suffice to be within a Degree or two of the truth; whereas in the other Method of Shooting he ought to be very curious. But a Third, and no less considerable Advantage is, in the saving the King's Powder, which in so great and so numerous Discharges, as we have lately seen, must needs amount to a considerable value. And for Sea-Mortars, it is scarce Practicable otherwise to use them, where the agitation of the Sea continually changes the direction of the Mortar, and would render the Shot
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very uncertain, were it not that they are placed about 45 Degrees Elevation, where several Degrees above or under makes very little difference in the Effect.

In *Numb.* 179. of these Transactions, I considered and demonstrated all the Propositions relating to the motion of Projectiles, and gave a Solution to this Problem, *viz.* *To hit an Object above or below the Horizontal Line with the greatest certainty and least force*, as may be seen in that Transaction, *p.* 16. & 17. That is, that the Horizontal distance of the Object being put $= b$, and the Perpendicular height $= h$, the Charge requisite to strike the Object with the greatest Advantage, was that which with an Elevation of 45° would cast the Shot on the Horizontal Line to the distance of $\sqrt{bb + hh} + h$ when the Object was above the Horizon; or if it were below it, the Charge must be lesser, so as to reach on the Horizon, at 45° Elevation, no greater a distance than $\sqrt{bb + hh} - h$, that is, in the one case, the Sum of the Hypothenuſal distance of the Object from the Gun and the Perpendicular height thereof above the Gun; and in the other case, when the Object is below the Horizon, the difference of the same, *per* 47. 1. *Eucl.* And I then shewed how to find the Elevation proper for the Gun so charged, *viz.* As the Horizontal distance of the Object, to the Sum or difference of the Hypothenuſal distance and Perpendicular height :: So Radius to the Tangent of the Elevation sought. But I was not at that time aware that the aforesaid Elevation did constantly bisect the Angle between the Perpendicular and the Object, as is demonstrated from the Difference and Sum of the *Tangent* and *Secant* of any Arch being always equal to the *Tangent* and *Cotangent* of the half Complement thereof to a Quadrant. Having discovered this, I think nothing can be more compendious, or bids fairer to compleat the Art of Gunnery, it being as easie to shoot with a Mortar at any Object on demand, as if it were

on the Level; neither is there need of any Computation, but only simply laying the Gun to pass, in the middle Line between the Zenith and the Object, and giving it its due Charge. Nor is there any great need of Instruments for this purpose: For if the Muzzle of the Mortar be turned truly Square to the Bore of the Piece, as it usually is or ought to be, a piece of Looking-glass Plate applyed parallel to the Muzzle, will by its Reflection give the true Position of the Piece; the Bombardier having no more to do, but to look Perpendicularly down on the Looking-glass, alongst a small Thread with a Plumbet, and to raise or depress the Elevation of the Piece, till the Object appear reflected on the same Point of the *Speculum*, on which the Plumbet falls; for the Angle of Incidence and Reflection being equal, in this case a Line at Right Angles to the *Speculum*, as is the *Axis* of the Chase of the Piece, will bisect the Angle between the Perpendicular and the Object, according as our Proposition requires. So that it only remains by good and valid Experiments to be assured of the force of Gunpowder, how to make and conserve it equal, and to know the effect thereof in each Piece; that is, how far differing Charges will cast the same Shot out of it; which may most conveniently be engraven on the outside thereof, as a standing Direction to all Gunners, who shall from thence forward have occasion to use that Piece: And were this matter well ascertained, it might be worth the while to make all Mortars of the like Diameter, as near as may be alike in length of Chase, Weight, Chamber, and all other Circumstances.

This Discovery that the utmost Range on an inclined Plane is, when the *Axis* of the Piece makes equal Angles with the Perpendicular and the Object, compared with what I have demonstrated of the same Problem in the aforesaid *Numb.* 179. does lead to and discover two very
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ready Theorems; the one to find the greatest Horizontal Range at 45° Elevation, by any Shot made upon any inclined Plane, with any Elevation of the Piece whatsoever: And the other to find the Elevations proper to strike a given Object, with any force greater than what suffices to reach it with the aforesaid middle Elevation. Both which being performed by one single Proportion, may be very serviceable to such as are concerned in the Practice of Gunnery, but are unwilling to trouble themselves with tedious and difficult Rules. The two Propositions are these.

P R O P. I.

A Shot being made on an Inclined Plane, having the Horizontal Distance of the Object it strikes, with the Elevation of the Piece, and the Angle at the Gun between the Object and the Perpendicular: to find the greatest Horizontal Range of that Piece, laden with the same Charge; that is, half the *Latus rectum* of all the *Parabolæ* made with the same *impetus*.

R U L E.

Take half the Distance of the Object from the *Nadir*, and take the difference of the given Elevation from that half; the Versed Sine of that difference subtract from the Versed Sine of the Distance of the Object from the *Zenith*: Then shall the difference of those Versed Sines be to the Sine of the Distance of the Object from the *Zenith*, as the Horizontal Distance of the Object struck to the greatest Horizontal Range at 45° .

P R O P. II.

Having the greatest Horizontal Range of a Gun, the Horizontal Distance and Angle of Inclination of an Object to the Perpendicular, to find the two Elevations necessary to strike that Object.

R U L E.

Halve the Distance of the Object from the *Nadir*, this half is always equal to the half Sum of the two Elevations we seek. Then say, *As the greatest Horizontal Range is to the Horizontal Distance of the Object: So is the Sine of the Angle of Inclination or Distance of the Object from the Perpendicular, to a fourth Proportional; which fourth being subtracted from the Versed Sine of the Distance of the Object from the Zenith, leaves the Versed Sine of half the difference of the Elevations sought; which Elevations are therefore had by adding and subtracting that half difference to and from the aforesaid half Sum.*

I shall not need to speak of the facility of these Solutions, I shall only observe that they are both General, without Exception or Caution, and derived from the knowledge that these two Elevations are equidistant above and below the Line bisecting the Angle between the Object and the *Zenith*.